



## Hardware Demonstration: Frequency Spectra of Transients

**August 9, 2017**

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# Acronym List

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CW	Continuous Wave
dB	Decibel
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
GSFC	Goddard Space Flight Center
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Center



# Introduction/Abstract


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- **Radiated emissions measurements as specified by MIL-STD-461 are performed in the frequency domain, which is best suited to continuous wave (CW) types of signals**
- **Non-CW signals can potentially generate momentary radiated emissions that may be missed with traditional measurement techniques**
  - Single event pulses/transients (e.g. ESD type events)
  - Low repetition rate signals
  - “Bursty”/modulated signals
- **Recent real-life event:**
  - A machine model ESD event occurred in the immediate vicinity of an antenna connected to an integrated satellite receiver
  - We had to assess coupling relative to radio front-end transient damage threshold
- **This demonstration provides measurement and analysis techniques that effectively evaluate the potential emissions from such signals in order to evaluate their impacts to system performance, damage thresholds, etc.**



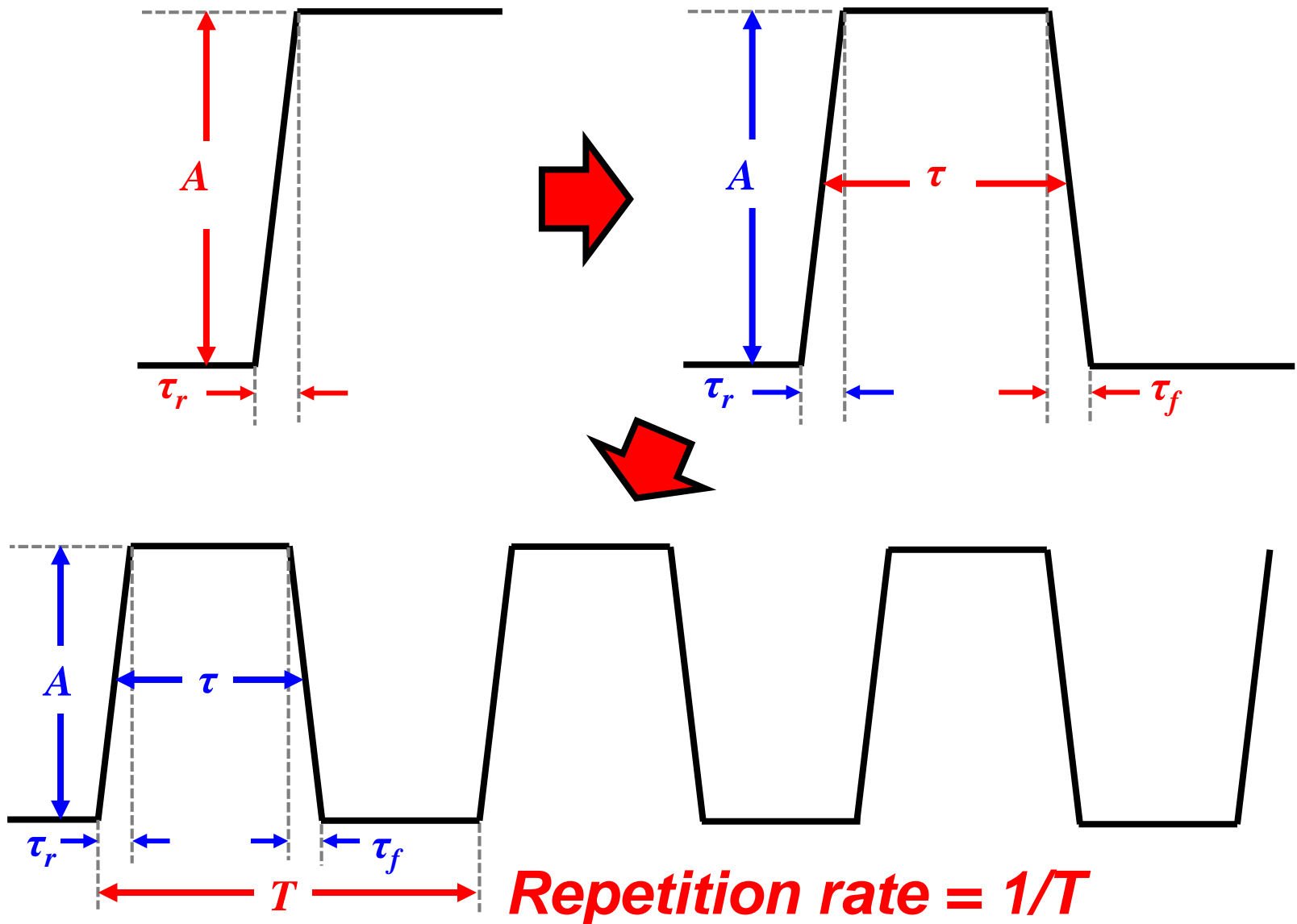
## This demo also touches upon...

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- Real-time spectral analysis
- Narrowband vs. broadband signals
- How your measurement technique can influence your result (*a touch of Heisenberg, perhaps?*)
- Analysis vs. test 



# Transients, Pulses, and Pulse Trains





# Frequency Spectra of Repeating Pulse Trains

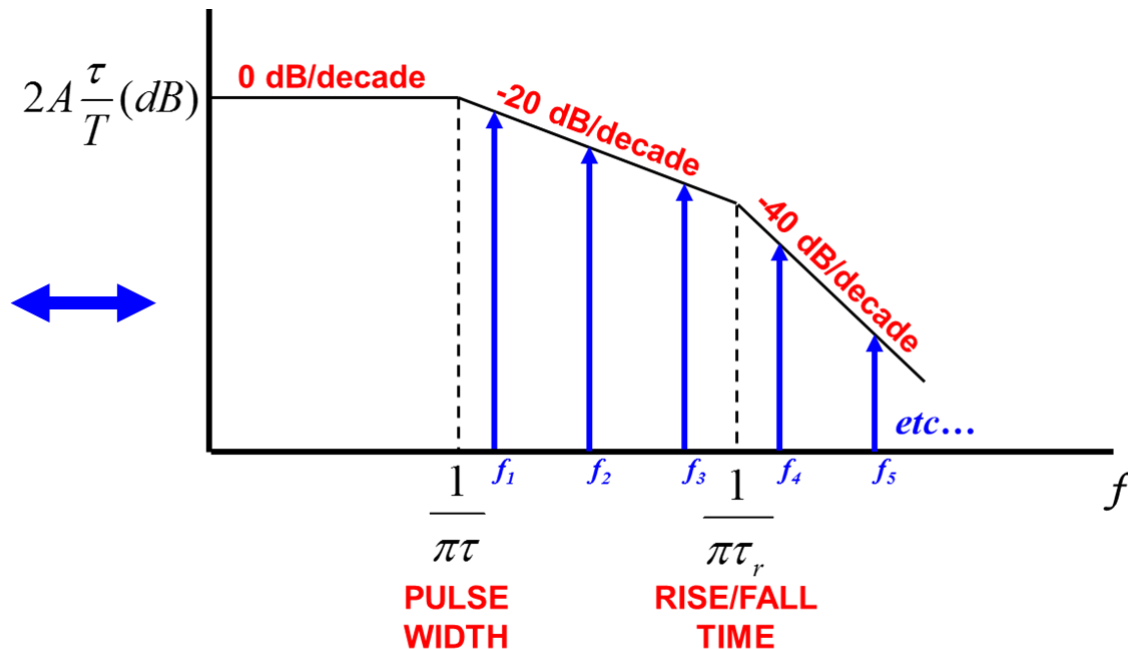
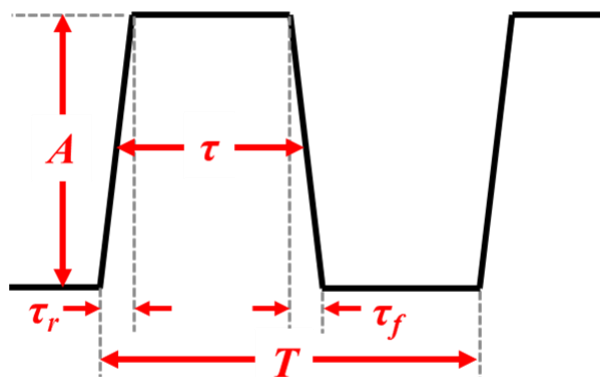
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- **Well understood, characterized, and documented:**
  - Clayton Paul, "Introduction to Electromagnetic Compatibility"
    - Sections 3.1 and 3.2
  - NESC Academy Video: "Effects of Rise/Fall Times on Signal Spectra", J. McCloskey
    - <https://mediaex-server.larc.nasa.gov/Academy/Play/f16370c89d3d437fa193b4013dbb5a4f1d>
  
- **Other NESC Academy videos:**
  - <https://nescacademy.nasa.gov/>
  - Type "McCloskey" in search bar



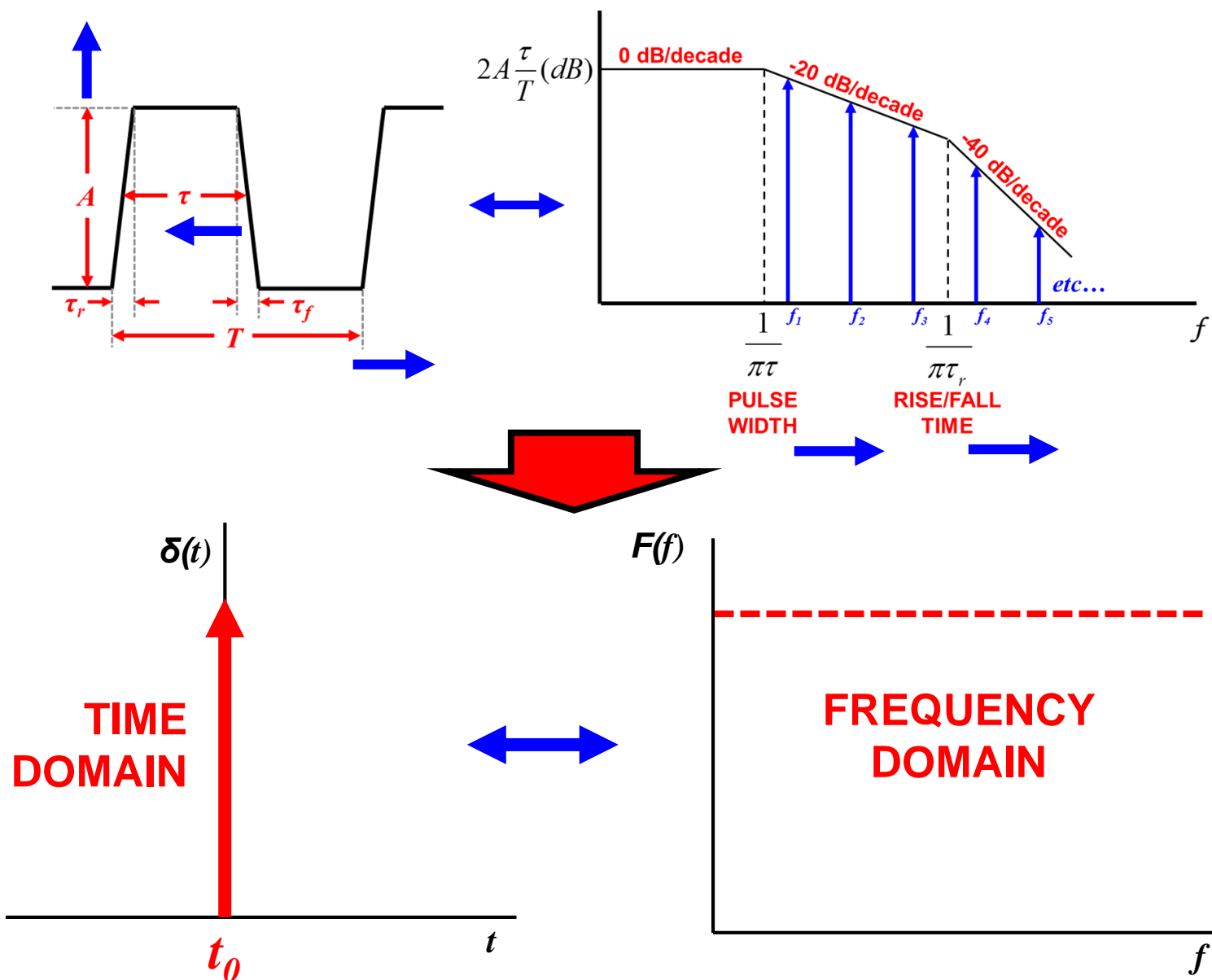
# Trapezoidal Wave: Time Domain vs. Frequency Domain

## TIME DOMAIN





# Ideal Impulse (cont.)







# Integral and Differential Properties of Fourier Transform

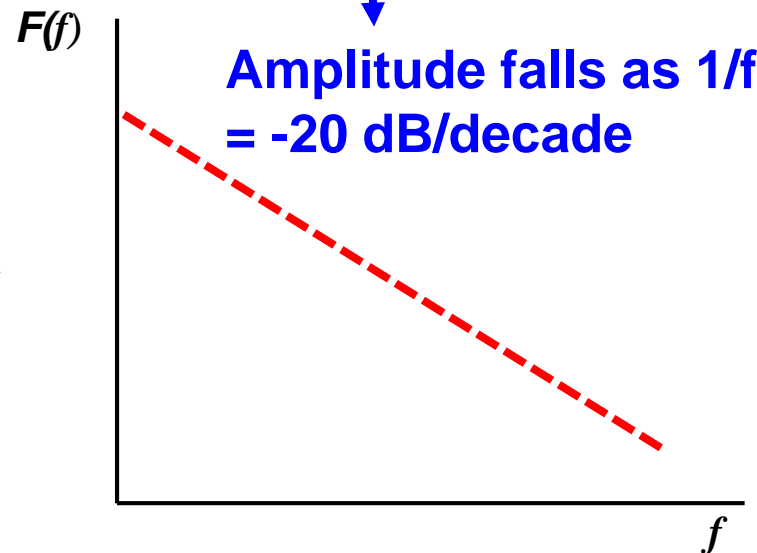
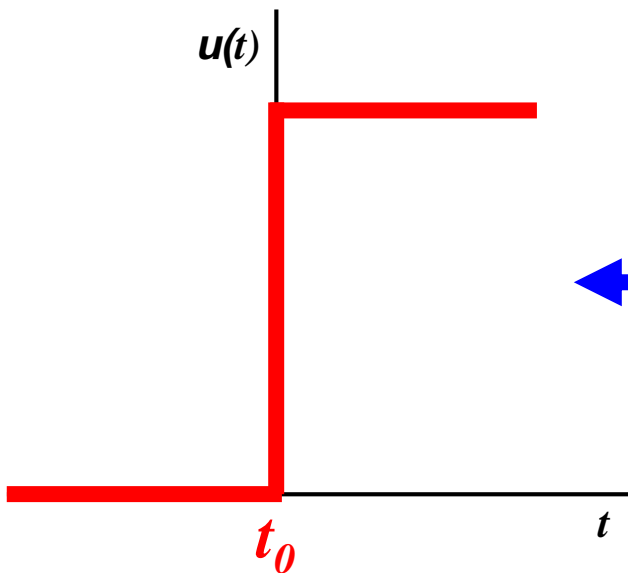
$$f(t) \leftrightarrow F(f)$$

$$\frac{df(t)}{dt} \leftrightarrow 2\pi j f \cdot F(f)$$

$$\int f(t) \leftrightarrow \frac{1}{2\pi j f} \cdot F(f)$$

**Unit step  
function:**

$$u(t) = \int \delta(t)$$

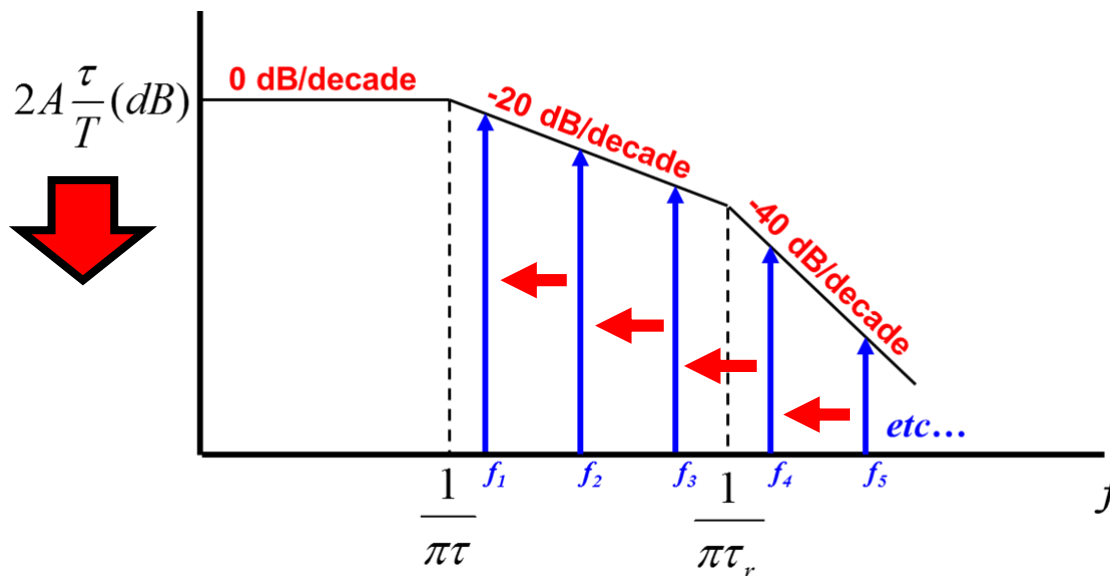


**Amplitude falls as 1/f  
= -20 dB/decade**



# Pulse Spectrum Dependence on Repetition Rate

- Single pulse may be modeled as a pulse train taken in the limit as:
  - $T \rightarrow \infty$  ( $f \rightarrow 0$ )
- For constant  $A$ ,  $\tau$ ,  $\tau_r$ , and decreasing repetition rate (increasing  $T$ ):
  - Spacing of harmonics decreases proportionally
  - Duty cycle  $\tau/T$  decreases proportionally
  - Amplitude of entire envelope decreases proportionally - *WHEN MEASUREMENT BANDWIDTH IS SUFFICIENT TO RESOLVE INDIVIDUAL HARMONICS*





## Demonstration 1: Pulse Spectrum Dependence on Repetition Rate

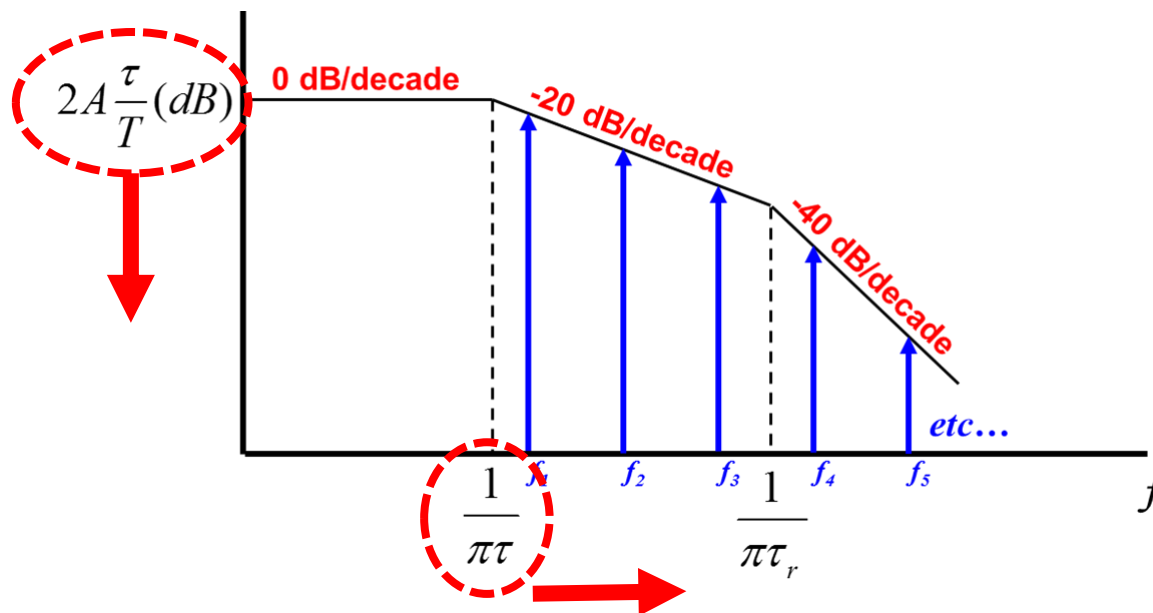
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- Frequency spectra with the following constant values:
  - $A = 1 \text{ V p-p}$
  - $\tau = 500 \text{ nsec}$
  - $\tau_r = \tau_f = 4 \text{ nsec}$
- Varying repetition rate: 1 MHz, 100 kHz, 10 kHz
- 1 kHz measurement bandwidth
  - *Sufficient to resolve individual harmonics*



# Pulse Spectrum Dependence on Pulse Width

- For constant  $A$ ,  $\tau_r$ ,  $T$ , and decreasing pulse width  $\tau$  :
  - Duty cycle  $\tau/T$  decreases proportionally
  - Amplitude of low frequency plateau decreases proportionally
  - First “knee” frequency  $1/\pi\tau$  shifts to right proportionally
  - Effects cancel for frequencies above “knee”
  - ENVELOPE OF HARMONIC CONTENT ABOVE FIRST “KNEE” FREQUENCY IS INDEPENDENT OF PULSE WIDTH





## Demonstration 2: Pulse Spectrum Dependence on Pulse Width

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- **Frequency spectra with the following constant values:**
  - $A = 1 \text{ V p-p}$
  - $\tau_r = \tau_f = 4 \text{ nsec}$
  - $T = 10 \text{ kHz}$
- **Varying pulse width: 500 nsec, 5  $\mu\text{sec}$ , 50  $\mu\text{sec}$**
- **1 kHz measurement bandwidth**
  - *Sufficient to resolve individual harmonics*



# MIL-STD-461G Table II

- *But...measurement bandwidth is not arbitrary...*

TABLE II. Bandwidth and measurement time.

Frequency Range	6 dB Resolution Bandwidth	Minimum Dwell Time		Minimum Measurement Time Analog-Tuned Measurement Receiver <sup>1/</sup>
		Stepped-Tuned Receiver <sup>1/</sup> (Seconds)	FFT Receiver <sup>2/</sup> (Seconds/ Measurement Bandwidth)	
30 Hz - 1 kHz	10 Hz	0.15	1	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015	1	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015	1	0.015 sec/kHz
150 kHz - 10 MHz	10 kHz	0.015	1	1.5 sec/MHz
10 MHz - 30 MHz	10 kHz	0.015	0.15	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015	0.15	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015	0.015	15 sec/GHz

*Used in Demonstration 3*



## A.4.3.10.3.2 (4.3.10.3.2) Emission identification.

*All emissions regardless of characteristics shall be measured with the measurement receiver bandwidths specified in [Table II](#) and compared against the applicable limits. Identification of emissions with regard to narrowband or broadband categorization is not applicable.*

**Discussion:** Requirements for specific bandwidths and the use of single limits are intended to resolve a number of problems. Versions of MIL-STD-461 and MIL-STD-462 prior to the “D” revision had no controls on required bandwidths and provided both narrowband and broadband limits over much of the frequency range for most emission requirements. The significance of the particular bandwidths chosen for use by a test facility was addressed by classification of the appearance of the emissions with respect to the chosen bandwidths. Emissions considered to be broadband had to be normalized to equivalent levels in a 1 MHz bandwidth. The bandwidths and classification techniques used by various facilities were very inconsistent and resulted in a lack of standardization. The basic issue of emission classification was often poorly understood and implemented. Requiring specific bandwidths with a single limit eliminates any need to classify emissions.

An additional problem is that emission profiles from modern electronics are often quite complex. Some emission signatures have frequency ranges where the emissions exhibit white noise characteristics. Normalization to a 1 MHz bandwidth using spectral amplitude assumptions based on impulse noise characteristics is not technically correct. Requiring specific bandwidths eliminates normalization and this discrepancy.



# Narrowband vs. Broadband?

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- **Q: What defines a signal as “narrowband”?**

- A's:

- When it has frequency content (e.g. harmonics) spaced sufficiently far apart that the measurement bandwidth can properly resolve it
- When you change the measurement bandwidth and get the same result

- **Q: What defines a signal as “broadband”?**

- A's:

- When it has frequency content (e.g. harmonics) spaced closer together than the measurement bandwidth can properly resolve
- When you change the measurement bandwidth and the level changes proportionately

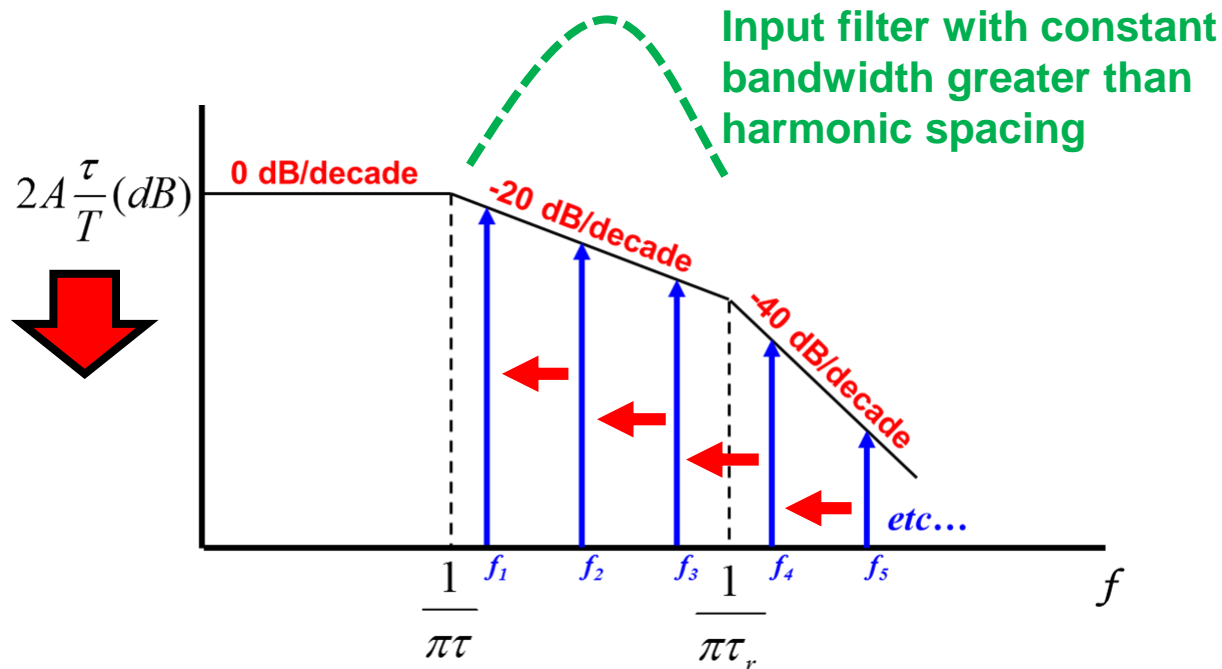
- ***IT'S ALL ABOUT BANDWIDTH!!!***





# Repetition Rate < Measurement Bandwidth

- What happens when we decrease repetition rate below measurement bandwidth?
  - Amplitude of entire envelope decreases proportionally
  - Spacing of harmonics decreases proportionally
  - Input filter with constant bandwidth sees constant broadband level





## Demonstration 3: Broadband Spectra for Repetition Rates Lower than Measurement Bandwidth

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- **Measure frequency spectra as indicated below using 2 methods:**
  - *Demo 3a: Standard spectrum analyzer mode using max hold*
  - *Demo 3b: Real-time spectrum analyzer mode*
- **Frequency spectra**
  - 30 – 50 MHz as example frequency range
  - 100 kHz measurement bandwidth per MIL-STD-461G Table II
  - Constant values:  $A = 1 \text{ V p-p}$ ,  $\tau = 500 \text{ nsec}$ ,  $\tau_r = \tau_f = 4 \text{ nsec}$
  - Repetition rate
    - 1 MHz stepped down to 100 kHz in 100 kHz increments
    - 10 kHz, 1 kHz, 100 Hz, 10 Hz, 1 Hz...
- **Demo 3c: Change measurement bandwidth with fixed (low) repetition rate**
  - Measured broadband signal is proportional to bandwidth



## Implications...

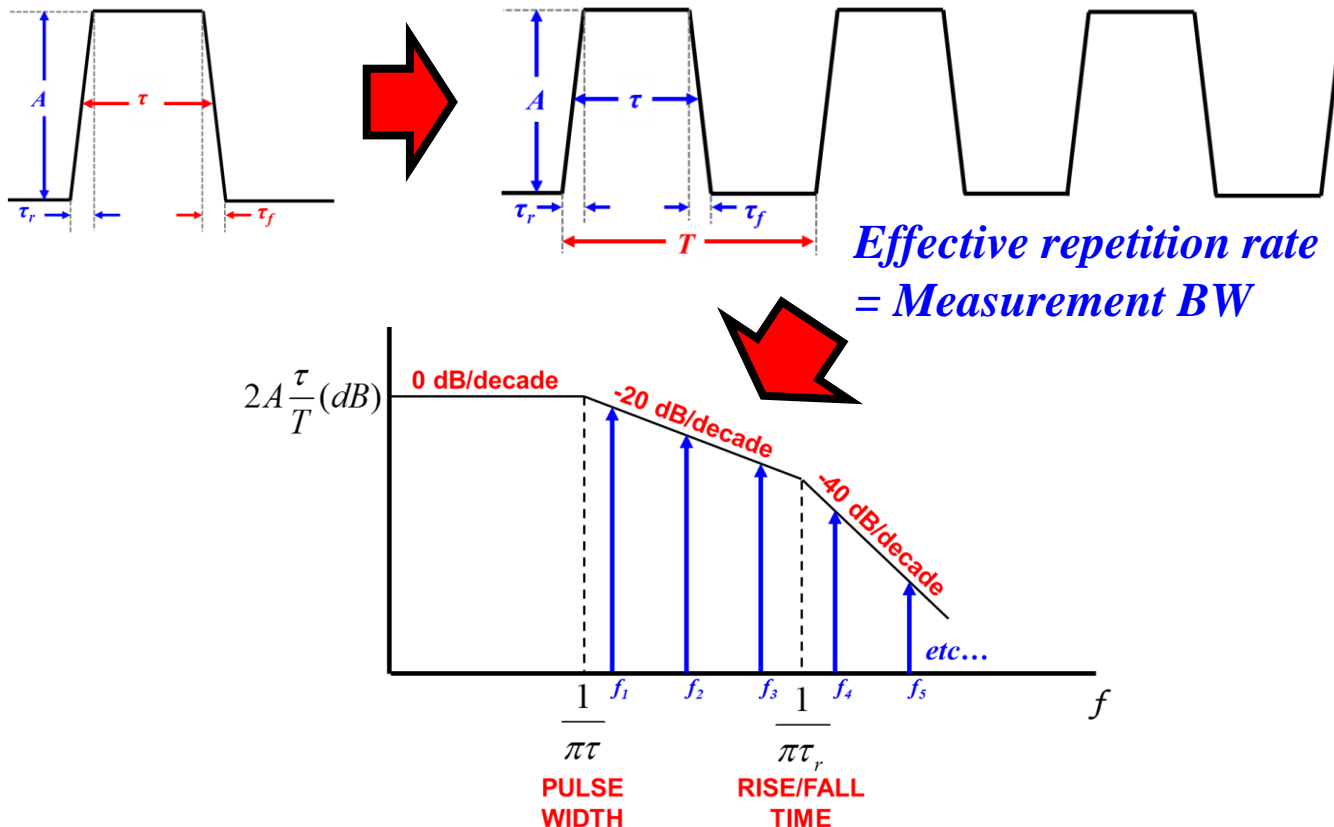
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- **When repetition rate is higher than measurement bandwidth:**
  - Individual harmonics can be resolved
  - It is a narrowband signal
  - Changing repetition rate changes frequency spectrum proportionally
- **When repetition rate is equal to or less than measurement bandwidth:**
  - Individual harmonics cannot be resolved
  - It is a broadband signal
  - With constant measurement bandwidth, broadband frequency spectrum is independent of repetition rate



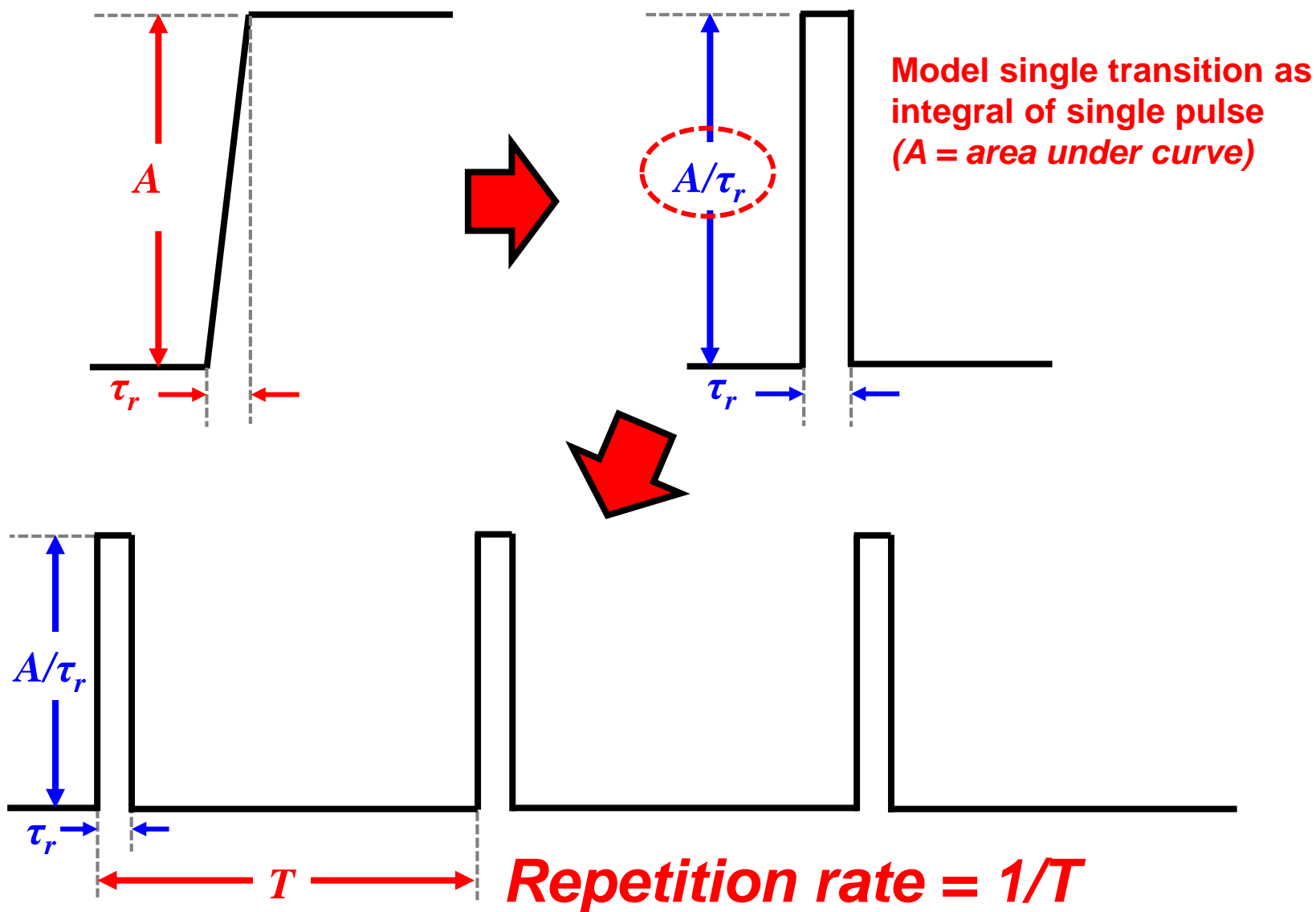
# Single Pulse or Low Repetition Rate Pulse Train

- Broadband spectra of low repetition rate signals may be measured with real-time FFT spectrum analyzer/receiver
- If such a unit is not available, high frequency broadband spectrum envelope for low repetition rate signals may be modeled as pulse train with effective repetition rate equal to the measurement bandwidth



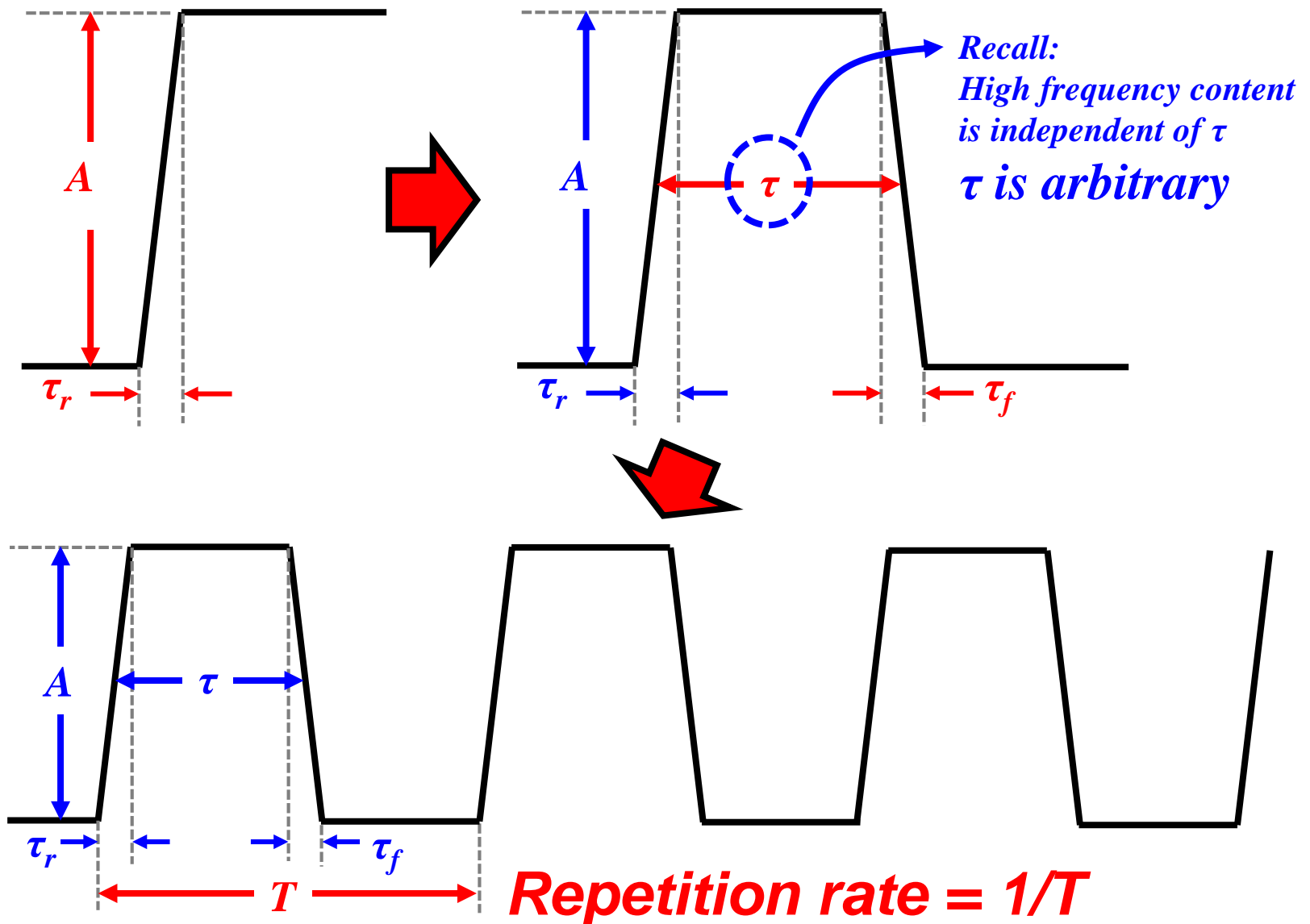


# Single Transient Model 1: Integral of Single Pulse



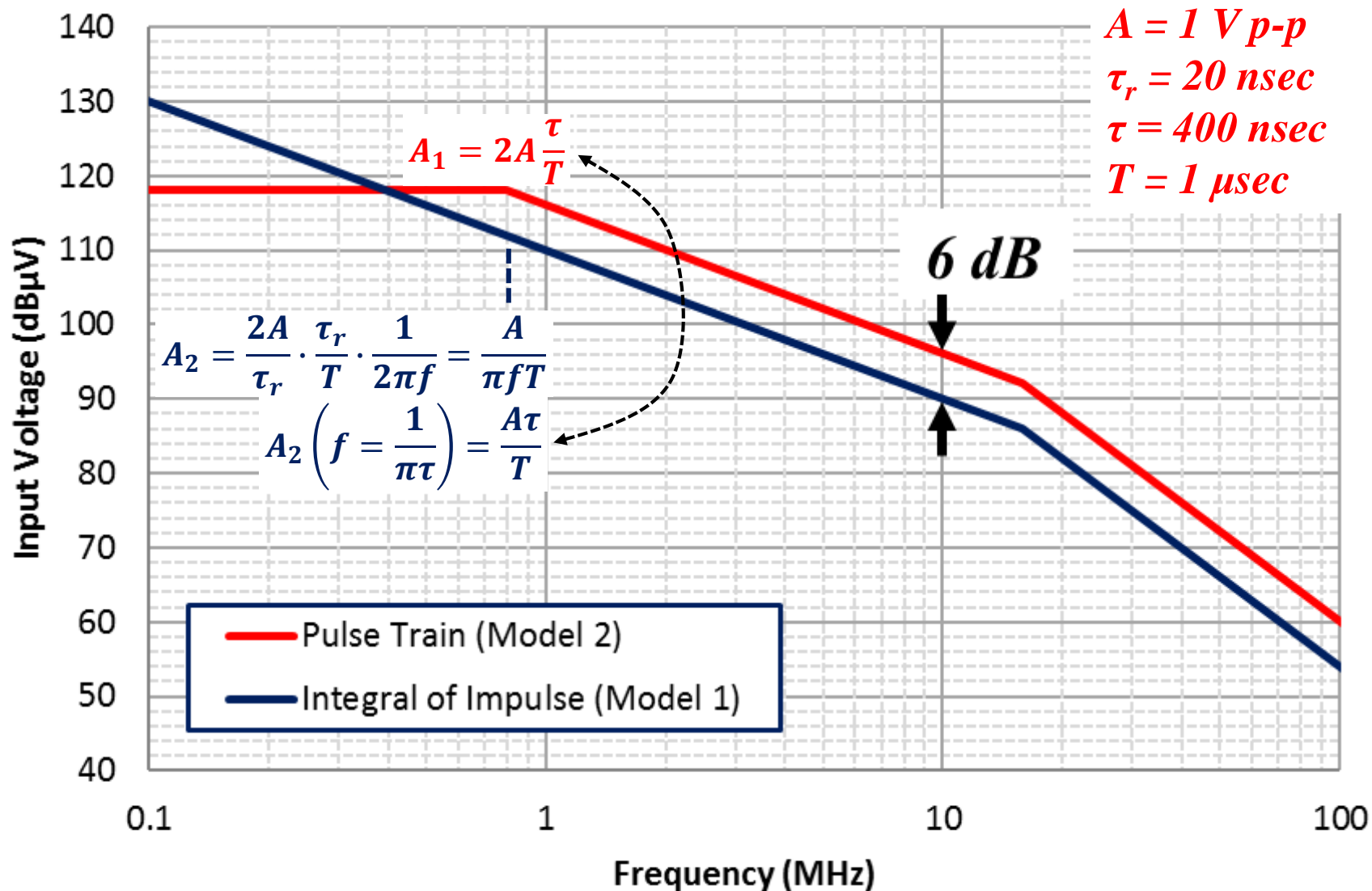


## Single Transient Model 2: Repeating Pulse Train with Same Characteristics as Transient





# Example Spectral Comparison Between Models





## Example Spectral Comparison Between Models (cont.)

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- Above first “knee” frequency ( $1/\pi\tau$ ), spectrum for pulse train model is 6 dB higher than integral of impulse model
- Integral of impulse model (Model 1)
  - More accurate
  - Mathematically more cumbersome
- Pulse train model (Model 2)
  - Mathematically simpler
  - Includes 2x actual number of transitions
  - Can use pulse train model and reduce by 6 dB to predict actual broadband spectrum (or keep 6 dB margin in your pocket)





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# THANK YOU!